AFRL-AFOSR-VA-TR-2017-0106

Magnet Coil Test Facility for Researching Magnetic Activity of Pico/Nano/ Micro Satellites (PNMSats)

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05/16/2017
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/RTB1

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
16-05-2017	Final Performance	30 Sep 2015 to 29 Sep 2016

4. TITLE AND SUBTITLE
Magnet Coil Test Facility for Researching Magnetic Activity of Pico/Nano/Micro Satellites (PNMSats)

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-15-1-0485

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
Sharanabasaweshwara Asundi

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
TUSKEGEE UNIVERSITY
58 TUSKEGEE UNIVERSITY
TUSKEGEE INSTITUTE, AL 36088 US

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AF Office of Scientific Research
875 N. Randolph St. Room 3112
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/AFOSR RTB1

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-AFOSR-VA-TR-2017-0106

12. DISTRIBUTION/AVAILABILITY STATEMENT
A DISTRIBUTION UNLIMITED: PB Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS
micro satellites

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			MOSES, JULIE
Unclassified	Unclassified	Unclassified	UU		19b. TELEPHONE NUMBER *(Include area code)* 703-696-9586

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Introduction

As capture in the proposal, the intent of this project was to develop a small-scale magnet coil test facility (MCTF) at Tuskegee University to facilitate the understanding of magnetic activity and experimental mapping of the magnetic field of pico/nano/micro-satellites (PNMSats). The MCTF was envisioned with the purpose to refine attitude determination, attitude control and communication capability of PNMSats and translate to increasing the technology readiness level (TRL) of these subsystems, thereby broadening the scope of PNMSats as utility spacecraft. The specific objectives of setting up the MCTF were (i) Research mapping of the magnetic field of PNMSats (ii) Research methods of designing “magnetically clean” PNMSats and (iii) Design/analyze the utility and limitation of magnetic booms for PNMSats.

MCTF at Tuskegee University

Since the award from U.S. Air Force Office of Scientific Research was an instrumentation grant, the major focus was to realize the proposed MCTF at TU. The proposed MCTF is setup in the Aerospace Science Engineering department at Tuskegee University and verified to be fully functional. The main Helmholtz Coil Cage and the controller are shown in Figure 1. The MCTF is designed around the 120 cm triaxial square Helmholtz C-spin coil system. It is capable of producing a B-field of up to ±1.5 Gauss in a volume of 30×30×30 cm^3 with a field uniformity of 99%. The 3-axis bipolar power supplies, capable of DC or AC at 100Hz, controls this system. The magnetic field direction, intensity and frequency are specified through control software in real-time. The control software facilitates ambient- field-cancellation to create a zero magnetic field environment within 2 − 3 mGauss A computer controlled rotating platform with angular resolution of < 10, facilitates magnetic mapping and emulate angular displacement of PNMSats on orbit. The facility is equipped with four precision 3-axis magnetometers (noise at 1Hz is < 1nT/rtHz) on a sliding platform for characterizing the magnetic field of PNMSats and calibrating flight magnetometers. Apart from setting up the MCTF at TU, the support has been of paramount importance in securing personnel support in the form of a Research Initiation Award (RIA) from the National Science Foundation (NSF). The PI would like to express sincere gratitude to his Program Manager, Dr. Julie Moses, who went out of her way to facilitate this

DURIP grant and pave way for the RIA from NSF.

Figure 1 - Magnet Coil Test Facility at Tuskegee University

Accomplishments

The major goals of the project were as follows:

- Set up an MCTF with the supporting systems and calibrate it.
- Train students to use the MCTF for carrying out experiments and collecting data.
- Perform experiments to collect magnetic field measurements of magnet(ic) systems representative of those used in pico/nano/micro-satellites (PNMSats) for the purpose of developing magnetic maps.

Major Activities:

The major activities carried out as part of this broader research are as follows:

1. A major research facility - equipped with state-of-the-art Helmholtz Coil (HHC) Cage, systems & specimens for testing, computers, a coil winding machine, etc - is setup. The HHC is custom designed and built to accommodate pico/nano/micro-satellites
2. Student training in the use of state-of-the-art system for space research and development is another major activity, which was accomplished as part of this research activity.
3. Although, not planned, collaborative cross-disciplinary research involving the College of Agriculture was initiated as a major activity of this research.

Specific Objectives:

The specific objectives achieved as part of this research are as follows:

1. Several students were recruited to work on the project and were trained to use the MCTF facility; one of them excelled in using the equipment on her own.
2. Several rounds of experiments were performed to gather data for - (a) simple bar magnet and (b) an electromagnet with provision to activate 250 turns and 750 turns.
3. The measurements are being visualized as maps but the complete three-dimensional (3D) representation is still being explored.

Significant Results:

The following are significant results of the project:

1. Several sets of data have been gathered, including those for simple bar magnets and representations of CubeSat attitude actuators (electromagnets).
2. Preliminary magnetic maps have been plotted using MATLAB suite of tools. However, these maps need to be refined and more complete visualization needs to be produced.

Parallel Achievements:

The following are some of the parallel achievement of the project:

1. An interesting collaboration was initiated as part of the project, which involved analyzing the effect of prolonged exposure to magnetic field on plant seeds. Four different plant seeds were exposed to magnetic field of varying duration and its effect on germination was assessed.
2. Research in the design of a multifunctional drag measurement system of which, a magnetometer boom is a significant component, is initiated. An extended abstract of the design has been submitted for AIAA's SPACE 2017 forum.

Opportunities for Training and Professional Development

The support has provided valuable insight for both the PI and his students.

1. The PI and his students have presented the outcome of research done using the MCTF at various forums, received valuable suggestions and potential collaborations.
2. Students, who were able to attend technical gatherings had a great opportunity to connect with their peer researchers, particularly from in and around Alabama/Georgia. They got to learn about the research being done at University of Alabama Huntsville (UAH) and University of Georgia, among others.

The results of the research and parallel activities have been presented at the following forums:

- NSF HBCU-UP PI/PD Meeting (Washington, DC), March 1st & 2nd, 2017, Hosted by the American Association for the Advancement of Science (Poster Presented)
- AIAA Alabama Aerospace Week @ Alabama State House (Montgomery, AL), March 2nd, 2017, Organized by the AIAA Greater Huntsville Section (Poster Presented)
- Joint Annual Research Symposium, March 17th, 2017, Facilitated by Tuskegee University Office of Undergraduate Research (Poster Presented)
- AIAA Region II Student Conference (Starkville, MS), March 21-22, 2017, Hosted by Mississippi State University AIAA Student Chapter (Poster Presented)
- AIAA SPACE Forum 2017, Hosted by American Institute of Aeronautics and Astronautics (Abstract Submitted)

Impacts

The support from AFOSR has been deeply impactful to Tuskegee University. From facilitating a state-of-the-art equipment setup at TU to training future space engineers and encouraging multi-disciplinary activity, the support has had a wide impact.

Impact on the Development of the Principal Discipline

Foundationally, magnetic field maps of PNMSats is a poorly understood and/or accommodated for a majority of the missions. This problem has existed for over a decade now but limited effort has been made to address it. The solution being sought through this research will significantly aid in defining boundaries for PNMSats where the problem is manageable. The results until now, demonstrate that something like a "magnetic red zone" may be recommended for any PNMSat. A magnetically sensitive sensor, instrument may not function well if placed within this red zone. The basic understanding of magnetic fields of PNMSats and leading towards a representation similar to Geo-magnetic models (World Magnetic Model, International Geomagnetic Reference Model) will add a

new perception to the design of a PNMSat. The understanding will positively impact the refinement of CubeSat attitude actuators and sensors. The proposed research may have implications in designing methods of mapping magnetic fields of nearby planets, moons, asteroids, and such.

Impact on Other Disciplines

As stated in the previous sections, cross-disciplinary research has been initiated. It is well understood that life form is always under the influence of electro-magnetic force, which is one of the fundamental forces in nature. An ability to artificially alter the intensity or direction of this force in an environment and subjecting life form to this altered environment may impact our understanding of that life form or life in general. Preliminary results, although not conclusive, have shown that exposing one kind of plant seed to varying durations of exposure to this altered environment is positively affecting its germination. More experiments are planned and further study is being done to understand this phenomenon.

Impact on the Development of Human Resources

Tuskegee University is an aspiring institution and the only accredited Aerospace Engineering Program at an HBCU. For a long time, the program has predominantly focused on research in aeronautics. This research is changing that paradigm and generating interest in space systems research. Coupled with the courses being taught in Space Systems Engineering (Satellite Design), students have an option to get trained as space engineers and affect the workforce accordingly. Two of the students, one being an African American female, are very inclined to pursue their careers in space systems engineering. Efforts are on to get one of the students as an Engineering Trainee at NASA Goddard Space Flight Center. For a typical graduating class of 15-20 students per year, successfully motivating even two students to take up careers in Space is noteworthy. Apart from inspiring students to take up careers in Space, the project has also enabled a long time staff member in the Department of Aerospace Science Engineering at TU to reignite his interest in Space research and development.

Impact on Physical Resources

The MCTF academic facility is unique and probably the only one of its kind in the state of Alabama. The research facility has not only made opportunities available for the PI's department, but at least a couple of more collaborators - one from the College of Agriculture and another form College of Arts and Science - may be benefitted by it. It is an asset to showcase to visitors and potential collaborators when they tour TU's Aerospace Science Engineering's lab facilities.

Conclusion

When the research and capability is introduced to potential recruits and their parents, they're most impressed with TU's progress. On several occasions, the research facility has been showcased to Alumni and they've expressed elation with regards to the progress being made in space research at TU. The research conducted through the use of MCTF has facilitated internship opportunities at NASA Goddard Space Flight Center. If one or more of these opportunities get converted to full time positions, it may be the biggest impact of this project. It'll inspire many more in the loop to consider space systems engineering and do so at an organization like NASA.

Again, the PI and his team at Tuskegee University would like to express their deep gratitude to Dr. Moses and her team at AFOSR for making this a reality at Tuskegee University. The support has been paramount in initiating space research at TU and pave way for more support from AFOSR, NSF and other federal agencies.